ECE 441

SAMPLE FINAL EXAM

Name:___________________________

SSN:_____________________________

Theory:

1) For the BJT, indicate which of the following statements are correct: (4 POINTS)
a) The base Gummel Number is the total concentration (per cm^2) of minority carriers in the base (Y/N?)
b) The emitter is more heavily doped than the base to increase the emitter efficiency (Y/N?)
c) The use of a heterojunction at the emitter junction increases the emitter efficiency because it increases the injection of minority carriers in the base (Y/N?) and
d) reduces the injection of minority carriers in the emitter (Y/N?)
e) The collector is less doped than the base for
   - increasing the breakdown voltage at the collector junction (Y/N?)
   - preventing the Kirk effect (Y/N?)

f) Graded doping in the base shortens the transit time (Y/N?)

2) In a MOS capacitor (2 POINTS)
a) the capacitance at flat band is equal to the oxide capacitance (Y/N?)
b) weak inversion occurs when the minority carrier concentration at the surface is equal or larger than the intrinsic concentration (Y/N?)
c) the condition for strong inversion is …………………………………………..
d) deep depletion occurs when…………………………………………………………
…………..

3) In the analysis of the current-voltage characteristics of a MOSFET, (2 POINTS)
a) the " gradual channel approximation"
   - assumes the gate capacitance varies gradually along the channel (Y/N?)
   - assumes the threshold voltage is constant and equal to its value at the source of the device (Y/N?)

b) the bulk-charge effect ,
   - describes the variation of the depletion charge along the channel which affects the threshold voltage under transistor operation (Y/N?)
   - results in a saturation current lower than the charge control approximation (Y/N?)

Problem 1: BJT (8 POINTS)

The doping profile and the minority carrier concentration in the base of a PNP transistor in forward active mode are shown in the figure below. Assuming that the base is quasi-neutral, the built-in electric field is given by

$$= \frac{k_B T}{q} \frac{1}{N_d(x)} \frac{d}{dx} N_d(x)$$

a) Derive the expression of the drift current density of minority carriers in the base, in terms of the diffusion constant D_p.

b) Compute the total drift and diffusion current density of minority carriers $J_{tot}(x)$, and its average value $J_{av} = \frac{1}{x_B} \int_0^{x_x} J_{tot}(x) dx$

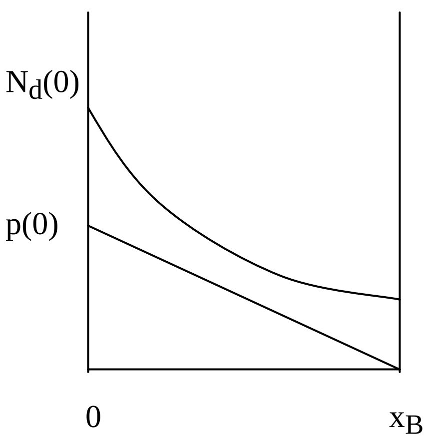
c) Find the transit time τ_{tr}=| Q_{st}/J_{tot}| of minority carriers in the base, where Q_{st} is the stored charge density of minority carriers.

d) Determine the gain enhancement due to the graded doping profile if the lifetime of the minority carriers τ_B remains the same

Useful formulas:

$$J_p = qp\mu_p - qD_p \frac{dp}{dx} \qquad \frac{D_n}{\mu_n} = \frac{D_p}{\mu_p} = \frac{k_B T}{q}$$

$$J_n = qn\mu_n + qD_n \frac{dn}{dx} \qquad \beta = \frac{\tau_B}{\tau_{tr}}$$



$$N_d(x) = N_d \exp(-\frac{x}{x_B})$$

$$p(x) = p(0)[1 - \frac{x}{x_B}]$$

Problem 2: MOS capacitor (5 POINTS)

The gate of a p-Si capacitor is made of highly n-doped poly-silicon so that the Fermi level is on the conduction band edge. On the semiconductor side, the Fermi level is 274 meV above the valence band. The oxide thickness is x_{ox}= 10 nm.

a) Draw the energy band diagram of the MOS capacitor at equilibrium, and indicate the value of the flat band voltage, $V_{FB.}$

b) If the oxide contains fixed negative interface charges of density Q_{it}, compute the change in the flat band voltage, $V_{FB.}$.

c) In addition, the oxide contains a uniform density of fixed positive charge ρ_0, compute the corresponding change in the flat band voltage, V_{FB}, and its total value taking the two kinds of charge into account.

d) Draw the profile of the electric field,   and electric potential, ϕ, across the whole MOS structure.

Data :	$q= 1.6x10^{-19}$ C	$\rho_0/q= 5.2x10^{16}/cm^3$
	$\varepsilon_0\varepsilon_s=1.04x10^{-12}$ F/cm	$Q_{it}/q= 2.08x10^{11}/cm^2$
	$\varepsilon_s/\varepsilon_{ox}=3$	E_g=1.124 eV

Useful formula: $V_{FB} = \Phi_{ms} - \frac{Q_{it}}{C_{ox}} - \frac{1}{C_{ox}} \int_0^{x_{ox}} \rho_0 \frac{x}{x_{ox}} dx$

Problem 3: MOSFETs (4POINTS)

A short channel MOSFET exhibits the C-V_G and transconductance characteristics shown in the figures below. Because of velocity saturation, the current-voltage relation is expressed as

$$I_{DS} = C_{ox}\frac{W}{L}\frac{\mu_0}{(1+\frac{V_{DS}}{L})}[(V_G - V_T)V_{DS} - \frac{V_{DS}^2}{2}]$$

which at saturation gives

$$I_{DS}^{SAT} = C_{ox}\frac{W}{2L}\mu_0 V_{DSAT}^2 \quad with \quad V_{DSAT} = L[\sqrt{1+2\frac{V_{GT}}{L}} - 1]$$

Here   is the critical field for velocity saturation.

a) Derive the expression of the transconductance $g_m = \frac{\partial I_{DS}^{SAT}}{\partial V_G}$ at current saturation.

b) Determine the surface mobility μ_0 (HINT: Analyze the curve $g_m(V_G)$)
c) Determine the value of the critical field   (HINT: consider g_m asymptotic limits)
d) Determine the value of the saturation velocity.

Numerical data: W=10 µm
L=1 µm

Useful formula: $\frac{1}{\sqrt{1+x}} \approx 1 - \frac{x}{2} \quad for \quad x << 1$